is now a morning star, but until August it remains too near the Sun to be easily seen even with a good telescope.

August is the month for the *Perseid* meteors, and the watcher for them will be able to see a good many during any clear night, especially during the second week of the month.

AN APPLICATION OF THE CROSSLEY REFLECTOR OF THE LICK OBSERVATORY TO THE STUDY OF VERY FAINT SPECTRA.*

By H. K. Palmer.

While engaged in photographing the brighter nebulæ with the Crossley reflector, the late Professor Keeler noted the great relative photographic brightness of the central stars in the ring nebulæ in *Lyra* and *Cygnus*—a fact indicating that the spectra of these stars contain an unduly large proportion of actinic rays. He tried to examine their spectra, both with a direct-vision spectroscope and with a prism held in the path of the rays, but in neither case was the spectrum bright enough to be seen. He therefore decided to construct a spectrograph for the study of these objects.

Such an instrument, to preserve and utilize the enormous advantages of the silver-on-glass reflecting telescope for work in the violet and ultra-violet regions, called for a design radically different from those of conventional spectroscopes. It would evidently be difficult for a star near the limits of vision to be centered and kept upon a narrow slit; the method of guiding by means of a reflecting slit would not answer; and it would be important to avoid the usual losses due to a slit. The instrument as originally designed consisted, in outline, of a 50° quartz prism with circular aperture of 27^{mm}, placed directly in the converging beam of light from the great mirror, at a distance of 15^{cm} inside the focus; of a plate-holder suitably placed; and of a guiding eye-piece working on the same principle as that employed in ordinary nebular photography.

Director Keeler had thought that by placing the prism

* Abstract from Lick Observatory Bulletin No. 34.

approximately at minimum deviation for the ray coinciding with the collimation axis, the confusion in the image, due to the very large angle of the cone of incidental light, would be so slight as not to interfere with the qualitative purposes of the instrument; especially since the dispersion would be small—only 3^{mm} from λ 350 to λ 500. It should be said, however, that he had doubts as to the success of this plan, but felt that it would be well worth a trial.

The spectograph was constructed by the observatory instrument-maker. It was completed on the day Professor KEELER left Mt. Hamilton for the last time, about a fortnight before his death.

A few weeks thereafter Dr. CAMPBELL and I tried the spectrograph, and found that the beam of light could not be brought to a focus. On account of the approaching opposition of *Eros,* and the plans for completing, if possible, Professor KEELER's program of photographing the brighter nebulæ during the following spring, the instrument was set aside until April, 1901.

Director CAMPBELL then asked me to design such changes in the instrument as would permit the insertion of a double concave quartz lens immediately in front of the prism, and of a double convex similar lens immediately behind the prism to receive the refracted rays and form the image on the sensitive plate. The lenses were constructed by the John A. Brashear Co., from constants supplied by Professor WADSWORTH. These additions to the optical train necessitated several changes in the support of the plate, in the guiding fixtures, etc. The alterations were completed by the instrument-maker on June 3d, and to me was assigned the duty of testing its capabilities.

It is only possible here to give a brief summary of the observations and the conclusions to which they have led, referring the reader to the original paper in Lick Observatory *Bulletin* No. 34 for the details, as well as for the full description, of the apparatus, its adjustments, and the method of observing.

As soon as the spectrograph was completed and adjusted, photographs were taken of the spectra of various objects to find out for what work an instrument of this kind is best

adapted; and to determine its limitations. It is evident that, because of the small dispersion, it cannot as a rule be used to advantage on the dark-line spectra, but some stars have been photographed with dark bands, broad enough to show. This limits it very largely to bright-line spectra, though it has great value for determining the nature of very faint spectra of all kinds. Moreover, since there is no slit, the object must not be so large that the various monochromatic images will overlap too much, and this condition confines the field to objects no larger than planetary nebulæ.

Large numbers of objects having various spectral types promised to yield valuable results; but on account of the limited time at my command, my program was confined, with the director's approval, to comparatively few objects. These included:—

(*a*) Such planetary nebulæ as were in observing position, both for purposes of comparison with results reached by observers using other instruments, and in the hope of discovering new features in the ultra-violet region. It was not expected that results obtained in the $H\epsilon$—$H\beta$ region of bright objects, by observers using large telescopes and powerful spectroscopes, would be surpassed or even equaled, on account of the feeble dispersion of this instrument.

(*b*) Such new stars as were in observing position.

(*c*) The central star in the ring nebula in *Lyra,* and other similar stars and stellar nuclei.

(*d*) A few Wolf-Rayet stars.

Altogether, twenty-one nebular spectra were photographed by me between June and September, 1901. After my departure, Mr. JOEL STEBBINS, Fellow in the Lick Observatory, kindly secured for me with the same instrument some very good spectrograms of *Nova Aurigæ, Nova Persei,* and a Wolf-Rayet star.

Examination of these spectrograms shows that in general the intensity of the continuous spectrum of the nebulæ has a minimum between $H\delta$ and $H\gamma$. This fact is confirmed by nearly all the negatives, and is too general a characteristic to be passed without notice. It seemed hardly possible that the spectrum of the nucleus, to which it was supposed that this belonged, should have an absorption band at this place, and

another explanation was sought. This was found by plotting Dr. CAMPBELL'S observations of G. C. 4390 on the same scale, and comparing the result with the spectra obtained with the slitless spectrograph. His observations were made with a large spectroscope attached to the 36-inch refractor. Inspection of this spectrum showed that he found the bright lines much fewer in the region where the continuous spectrum is weak in the spectrograms taken with the small instrument. His observations of N. G. C. 7027 give the same results. From this it seems safe to infer that the apparently greater relative strength of my spectrograms in the $H\gamma$—$H\beta$ region is largely due to the presence of many faint overlapping bright lines, whereas, in the region $H\delta$—$H\gamma$ fewer bright lines exist. A further support of this theory is afforded by nebulæ N. G. C. 6826 and N. G. C. 6891, each of which has a stellar nucleus. In each case the spectrum of the necleus has an almost uniform intensity throughout its entire extent.

One of the marked advantages of the reflector and quartz prism and lenses over the great refractor and glass optical train in spectrum observations is revealed by this comparison. Even in the favorable nebula G. C. 4390, CAMPBELL'S results stop at $H\zeta$, whereas the slitless spectrograph record extends to about λ 337.

One of the principal purposes of this investigation was to determine the efficiency of the slitless quartz spectrograph attached to the Crossley reflector, for the photography of very faint spectra. Its power in this respect is surprisingly great. It is well illustrated in the case of *Nova Cygni.* The visual magnitude of this star was estimated by Professor BARNARD in 1901 to be 15.5. My four-hour exposure, with fair following and focus, recorded its continuous spectrum in good strength, well up into the ultra-violet. The character of the spectrum could have been determined had the image been considerably less intense. This spectrum may be relatively stronger in the photographic regions than ordinary stellar spectra, though the spectra of many adjacent 15th-magnitude stars are recorded satisfactorily on the same plate. It would be perfectly practicable to carry the exposures up to ten hours or more; the guiding could be more accurate, now that the principal sources of the irregularity in diurnal motion have been removed;

and perhaps the more stable new telescope mounting will eliminate the present unfortunate changes in the focus during exposures. Considering these facts, I am reasonably confident that this instrument can record the continuous spectrum of the faintest star visible in the 36-inch telescope under the corresponding atmospheric conditions. Further, in the case of stellar nebulæ, etc., whose spectra contain well-defined bright lines, I do not doubt that the instrument will record the principal bright lines of objects too faint to be seen in our most powerful telescopes.

It is only for work on very faint spectra that this spectrograph is efficient. Its dispersive power is very low, and it should seldom be used on spectra, or on those portions of spectra bright enough to be recorded by relatively longer exposures with instruments giving greater dispersion.

For qualitative studies of general spectral features, this spectrograph is efficient on all spectra, whether continuous or bright line; but for quantitative results its usefulness is limited largely to small and faint bright-line spectra.

For most of the objects observed, a 60° prism, and for some of the objects two 60° prisms would have been an improvement over the present 50° prism; requiring, of course, the reconstruction of the instrument.

For some of the stellar bright-line objects a convex lens of twice the present lens's focal length would have had an advantage in separating close lines on the photographic plate, permitting at the same time more accurate determinations of wave-lengths. This would probably alter the character of the field of the combination somewhat.

It is possible that a similar instrument on twice the linear scale, *i. e.,* with lenses and prism having 50^{mm} apertures,—with perhaps a 60° prism,—would be efficient and practicable for the objects of medium brightness on my list.

New nebular lines at $\lambda\,337$ and $\lambda\,345$ were discovered. These lines were later found to exist in the spectrum of *Nova Persei,* from the plate taken October 14, 1901. The nebular character of the *Nova* spectrum is thus established for the extreme ultra-violet region, as had previously been done for the other regions.

The spectrum of *Nova Cygni,* which in 1876 was of the usual "new-star" type, and later changed into the nebular type, has now become continuous, with no signs of bright lines.

The bright lines in the nebular spectrum of *Nova Aurigæ* are now relatively faint, and the spectrum appears to be approaching the continuous type.

These complete and astonishingly rapid changes of spectral types observed in the cases of *Nova Cygni* and *Nova Aurigæ*,—and likewise those observed in *Nova Normæ, Nova Sagittarii, Nova Persei,* etc.,—leave little doubt that the masses of these objects are small.

All the new stars of recent years should be reobserved with this spectrograph every year, to keep account of the progressive changes in their spectra. The importance of carrying out this plan can scarcely be overestimated.

The relative intensities of nebular and other bright lines, as well as of continuous spectra, are shown more accurately on the plates secured with this spectrograph than on those made with instruments absorbing the blue and violet very strongly.

The spectrum of the central star in the ring nebula in *Lyra* seems to be not of an unusual type, unless perhaps it contains a bright line near λ 373. It is quite possible that the star is somewhat brighter photographically than visually; at least, photographic evidence is not opposed to this theory.

The great intensity of the λ 373 ring in the ring nebula perhaps explains one point in nebular photography. Professor KEELER found that for most nebulæ an exposure of three hours gave the best results, whereas the best photograph of the ring nebula was obtained in ten minutes. While the ring nebula is brighter than the average bright nebula, this brief exposure of ten minutes is out of proportion to its visual brightness; but its radiation being mostly in the ultra-violet, it should have a somewhat greater photographic than visual brightness.